

Some Features Of The Plane Couette Flow

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Abstract. In the previous paper [1] it was found, in particular, that in the transition regime of the plane Couette flow the values of total energy flux and shear stress may exceed the corresponding free molecular values. For parameters of the problem (temperature ratio and speed ratio) considered in that paper, the discussed effect was sufficiently small (several percent). The present paper is devoted to more detailed investigation of this effect.

INTRODUCTION

The plane Couette flow represents one of the simplest classical problem with the main features typical of a real flow with friction and heat transfer. Due to its one-dimensional character, the Couette flow is widely used for the purposes of testing the numerical algorithms [2].

In spite of many investigations of the plane Couette flow, some of its important features need to be studied more thoroughly. One of these features is the effect that in transition regime of the flow the values of total energy flux and shear stress may exceed the corresponding free molecular values [1]. As far as we know, this effect was not described previously.

For parameters of the problem (temperature ratio and speed ratio) considered in Ref. [1], the discussed effect is sufficiently small (several percent). In the present paper the more detailed investigation of this effect is made.

PROBLEM FORMULATION

The steady one-dimensional flow of monatomic gas between two parallel plates is considered. One of the plates with the temperature T_1 is fixed, while another with the temperature T_2 is moving with the velocity U_2 . For given molecular model the problem contains three determining parameters: the temperature ratio T_2 / T_1 , the speed ratio $S = U_2 / (2RT_1)^{1/2}$ and the Knudsen number $Kn = \lambda / L$, λ being the mean free path and L – the distance between plates.

The problem is considered for solid spheres molecular model for the range of the Knudsen number $0.1 \leq Kn \leq 100$. The ratio T_2 / T_1 was varied in the range $1 \div 10$, while the speed ratio S – in the range $3 \div 30$.

Standard no-time-counter DSMC method [2] was employed to simulate the motion and collision of molecules. The surfaces of plates are assumed to be diffusely reflected. The estimation of total energy flux Q and shear stress τ was made using the sampling procedure that is based on the time that molecule stays in the cell. This procedure is shown to give the most accurate results of estimation [1].

Most of the results were obtained for uniform grid with $N = 100$ cells with total number M of simulated molecules being equal to 10^4 . Some variants were recomputed with $N = 200$ and $M = 4 \cdot 10^4$. As a result of test experiments the accuracy of the obtained results for Q and τ is estimated to be better than 0.002. The results for Q and τ are presented below in the form of ratio of these values to corresponding values Q_f and τ_f for the free molecular flow.

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RESULTS AND DISCUSSION

Fig. 1 illustrates the dependencies of Q / Q_f from the Knudsen number for the case $T_2 / T_1 = 1$ for 8 values of speed ratio S in the range $3 \div 30$. It is known, that for the plates with equal temperatures the relation $\tau / \tau_f = Q / Q_f$ takes place. In the simulations this relation was fulfilled with high accuracy.

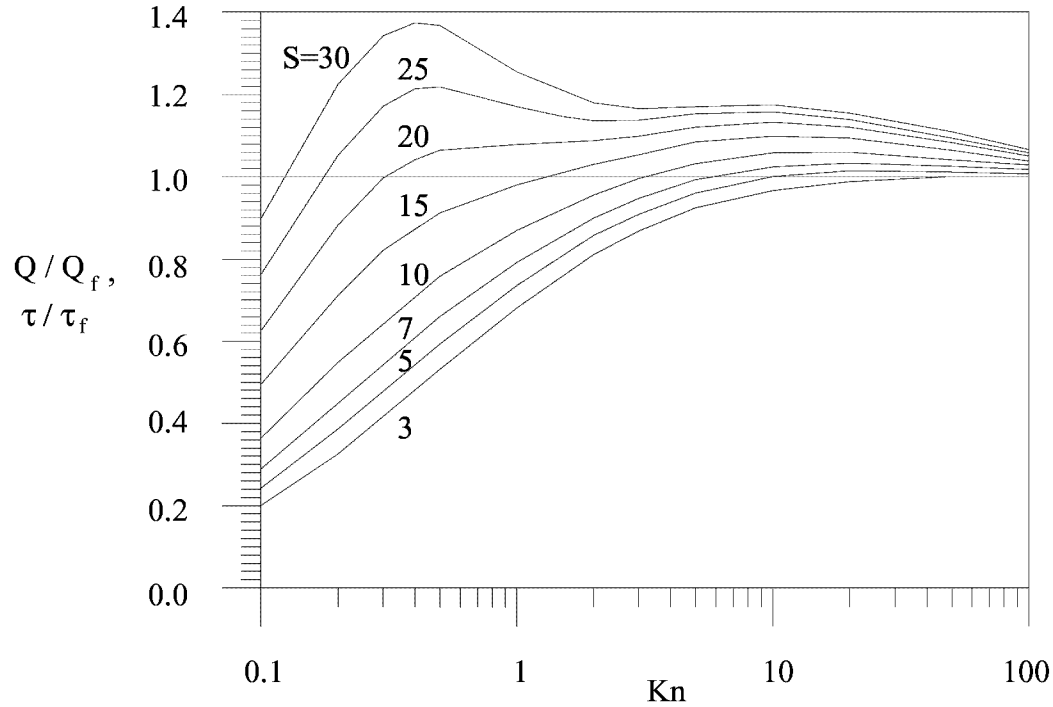


FIGURE 1. Q / Q_f and τ / τ_f as a function of the Knudsen number for $T_2 = T_1$.

As can be seen from the presented data, for any Knudsen number the monotonous increase of Q / Q_f with increasing of S takes place. The studied effect ($Q / Q_f > 1$) is observed for $S > 5$. For $S = 30$ the maximum value of the effect is about 40% at $Kn \approx 0.4$. It is evident, that the effect will increase with further increasing of S .

An interesting and unexpected feature of the presented dependencies consists in the changing of their shape at high values of S . Thus, at $S > 25$ the dependence $Q(Kn) / Q_f$ have two maxima – at $Kn \approx 0.4$ and at $Kn \approx 10$. Further investigations are needed to explain these peculiarities.

The rearrangement of the flow caused by changing the ratio T_2 / T_1 at constant S is illustrated in Fig. 2, where the dependencies of Q / Q_f (solid lines) and τ / τ_f (dashed lines) from Kn for $S = 30$ and three values of T_2 / T_1 (1, 2 and 10) are presented. The curve for $T_2 / T_1 = 1$ is the same as presented in Fig. 1. For the case with $T_1 \neq T_2$ the inequality $\tau / \tau_f < Q / Q_f$ takes place, but the difference between these quantities is small (see Fig. 2).

As can be seen from Fig 2, at $S = 30$ the increasing T_2 / T_1 results in the transformation the curve with two maxima into the curve with one maximum at $Kn \approx 1$.

For heat transfer problem, that represents a special case of Couette flow with $S = 0$, the studied effect also take place at sufficiently high temperature ratio. Thus, at $T_2 / T_1 = 100$ the heat flux Q 1.028 times exceeds its free molecular value Q_f at $Kn = 1$.

The studied effect reflects the complex character of rearrangement of the distribution function from Navier-Stokes type at low Knudsen numbers to two half-Maxwellian one in the free molecular limit.

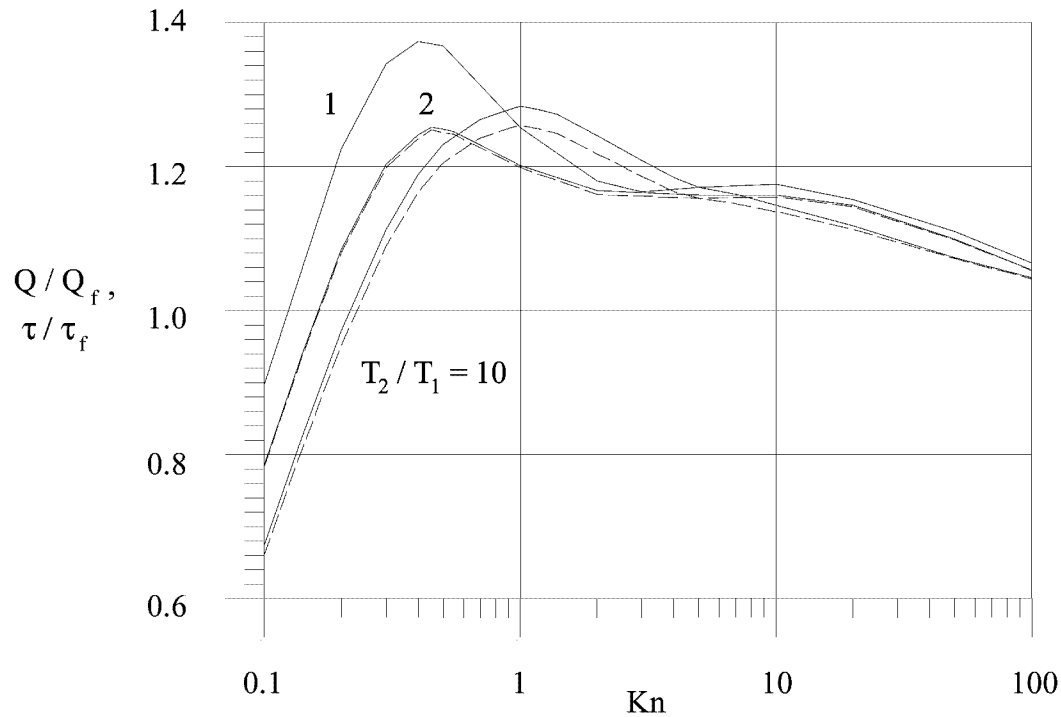


FIGURE 2. Q / Q_f and τ / τ_f as a function of the Knudsen number for $S = 30$.

CONCLUSION

1. In the transition regime of the plane Couette flow the values of total energy flux and shear stress may significantly exceed the corresponding free molecular values due to the complex character of rearrangement of the distribution function from Navier-Stokes type at low Knudsen numbers to two half-Maxwellian one in the free molecular limit.
2. For the plates with equal temperatures the effect takes place for the range of speed ratio $S > 5$. For $S = 30$ the maximum value of the effect is about 40% at $Kn \approx 0.4$. For high values of S ($S > 25$) the dependence $Q(Kn) / Q_f$ have two maxima – at $Kn \approx 0.4$ and at $Kn \approx 10$.
3. For constant S the increasing T_2 / T_1 may results in the transformation the curve $Q(Kn) / Q_f$ with two maxima into the curve with one maximum at $Kn \approx 1$. For the case with $T_1 \neq T_2$ the inequality $\tau / \tau_f < Q / Q_f$ takes place, but the difference between these quantities is small.
4. For sufficiently high temperature ratio the effect is also observed for heat transfer problem ($S = 0$).

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